DOE would remove casks from service periodically for maintenance and inspection. These activities would occur at a cask maintenance facility(s) where cask functions and components would be checked and inspected in compliance with Nuclear Regulatory Commission requirements and preventive maintenance procedures. The major operations involved in cask maintenance would include decontamination, replacement of limited-life components such as O-rings, and verification of radiation *shielding* integrity, structural integrity, and heat transfer efficiency.

The large number of repository shipments would require new facilities for cask maintenance. DOE has not decided where in the United States it would locate a cask maintenance facility(s), but this EIS assumes that such a facility would be at the repository inside the Restricted Area at the North Portal on approximately 0.01 square kilometer (2.5 acres). Minor cask maintenance activities could occur at commercial or DOE sites.

2.1.4 ALTERNATIVE DESIGN CONCEPTS AND DESIGN FEATURES

DOE used the preliminary design concept in the *Viability Assessment of a Repository at Yucca Mountain* (DIRS 101779-DOE 1998, all), referred to as the Viability Assessment reference design, to evaluate impacts in the Draft EIS. While it was preparing the Draft EIS, DOE considered a broad range of design features and alternatives that would enhance the VA reference design within the License Application Design Selection process (DIRS 107292-CRWMS M&O 1999, all). In addition, the features and alternatives were combined into groups called *enhanced design alternatives*, each of which defined a unique design concept for the repository. DOE anticipated choosing an enhanced design alternative that it could carry forward to the licensing process.

The final *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all) recommended Enhanced *Design Alternative* II (EDA II) to carry forward in the design evolution. However, DOE did specify that backfill should be only a possible option in EDA II. Accordingly, DOE adopted EDA II without backfill as the design to be evaluated for the purpose of making a determination on site recommendation, as documented in the Science and Engineering Report (DIRS 153849-DOE 2001, all). EDA II without backfill, over a range of thermal operating modes, was evaluated in the Supplement to the Draft EIS and is also the basis for this Final EIS.

The following section qualitatively discusses potential future design features and alternatives. Appendix E provides further detail on alternative design concepts and alternatives and their potential environmental impacts.

2.1.4.1 Design Features and Alternatives To Control the Thermal/Moisture Environment in the Repository and To Limit Release and Transport of Radionuclides

Through successive evaluations and improvements, the repository design has evolved to the flexible design. This represents the current state of the ongoing process that identifies and develops ideas through conceptual, then preliminary, then more detailed designs to produce a design that DOE would use for purposes of the Secretary of Energy’s determination of whether to recommend approval of the Yucca Mountain site to the President for development of a geologic repository. Coupled with information from ongoing scientific tests and investigations, the design process continues to provide insights into how to improve repository performance and reduce uncertainties in performance projections.

A key to the determination on site recommendation is demonstrating whether a repository at Yucca Mountain would be likely to meet regulatory standards. To that end, scientific tests and studies identify and quantify uncertainties in performance assessment and confirm performance projections. Due to limitations in the understanding of natural processes that might occur over thousands of years, as well as the limits on being able to characterize the site fully, uncertainties in performance assessments can never be completely eliminated. DOE believes that the natural system and the robust flexible design would accommodate unquantified and residual uncertainties through performance margin (design and safety) and defense-in-depth. *Defense-in-depth* is a design approach that relies on a series of barriers, both natural and manmade, that would work in a complementary manner to minimize the amount of radioactive material that could eventually travel from the repository to the human environment.

Refining details of the design of the proposed repository is an ongoing and progressive process [see the Science and Engineering Report (DIRS 153849-DOE 2001, Section 2.1.2)]. As more information becomes available about the site, along with results from tests to evaluate the implementation of the design, DOE will continue to refine the repository design. To increase the level of confidence in the understanding of long-term repository behavior, scientific tests would continue throughout the periods before and during License Application (if the site was recommended and approved for development as a repository), construction authorization, repository operations, and performance monitoring. With the flexibility inherent in the design, periodic reviews of the results of the ongoing testing program and other design activities could prompt further design feature modifications.

As described in this chapter, DOE is considering a number of scenarios and operating modes, which are defined by key parameters that include the number of waste packages, spacing between waste packages, whether there would be surface aging, average linear thermal load, average maximum waste package temperature, emplacement period, emplacement area, length of emplacement and access drifts (as well as total excavated volume), drift spacing, and ventilation (forced-air and natural).

As an example of ongoing studies, DOE is examining the use of an extended period of natural ventilation of emplacement drifts after a period of forced-air ventilation. The heat generated by the spent nuclear fuel and high-level radioactive waste could develop and maintain a temperature difference to drive passive ventilation of the emplacement drifts throughout the maximum time the repository would remain open. The heat from the waste could be used to draw cooler, drier external air through the intake shafts, across the emplacement drifts, and out the exhaust shafts (located at an elevation above the intakes), much the way heat from a fireplace draws air from a room and exhausts it through a chimney. Passive ventilation is used to regulate air temperature in buildings and has similar uses in large subsurface structures such as mines. Findings in numerous caves that are analogous to a deep geologic repository (DIRS 153849-DOE 2001, Section 2.1.5.4) support the idea that the environment of a naturally ventilated underground system could, under certain conditions, preserve materials for several thousand years and could greatly reduce waste package degradation. Optimizing the repository design to accommodate natural ventilation could result in a reconfigured supply and exhaust scheme, additional shafts, and air control devices for the drifts. Changes at the surface would include additional Ventilation Shaft Operations Areas associated with ventilation and exhaust shafts, as well as access roads to the additional shaft locations.

Drift spacing could be greater or smaller than that presented for the analytical scenarios, and could influence the size of the emplacement area and the length of emplacement and access drifts, as well as the total excavated underground volume (see DIRS 153849-DOE 2001, Section 2.1.4). Drift spacing versus waste package spacing is a design trade-off to achieve lower heat output per unit volume of a repository. The effect of drift spacing on these related parameters would be less than the effect of waste package spacing in the analytical scenarios discussed in this EIS. Therefore, DOE did not perform a *quantitative* evaluation of the environmental impacts of variable drift spacing.

2.1.4.2 Design Features and Alternatives to Support Operational and Cost Considerations

Uncertainties in future funding profiles or the order of spent nuclear fuel or high-level radioactive waste shipments could result in development of the repository in a sequential or modular manner (that is, constructing the surface and subsurface facilities in portions, or "modules"). This approach would facilitate the ability to incorporate "lessons learned" from initial work into subsequent modules, reduce initial construction costs and investment risk, and potentially increase confidence in meeting the schedule for waste receipt and emplacement. DOE has requested that the National Research Council continue the study of possible repository development strategies (DIRS 153849-DOE 2001, Section 2.1.3).

2.1.5 ESTIMATED COSTS ASSOCIATED WITH THE PROPOSED ACTION

DOE has estimated the total cost of the Proposed Action to construct, operate and monitor, and close a geologic repository at Yucca Mountain, including the transportation of spent nuclear fuel and high-level radioactive waste to the repository (DIRS 156900-DOE 2001, all). The estimate is based on acceptance and disposal of about 63,000 MTHM of commercial spent nuclear fuel, 2,333 MTHM of DOE spent nuclear fuel, and 8,315 canisters of solidified high-level radioactive waste (4,667 MTHM). Table 2-5 lists the estimated costs. The total future costs from 2002 to closure for the flexible design would range from about $42.7 to $57.3 billion (in 2001 dollars). DOE is reporting future costs for comparison with the No-Action Alternative. Historical costs through 2001 are $8.8 billion (in 2001 dollars). The costs are representative and would vary somewhat, depending on the operating mode, packaging and transportation scenarios, and the Nevada transportation implementing alternative selected.

Table 2-5. Proposed Action costs from 2002 to closure.[a,b]

Description	Operating mode: Higher-temperature	Operating mode: Lower-temperature
Monitored geologic repository	31.5	37.4 - 43.1
Waste acceptance, storage, and transportation	4.3	4.3
Nevada transportation	0.8	0.8
Program integration	2.2	2.4 - 3.7
Institutional	3.9	4.1 - 5.4
Total	***$42.7***	***$49.0 - 57.3***

a. Source: DIRS 156900-DOE (2001, all).
b. Adjusted to 2001 dollars, in billions per DIRS 156899-DOE (2001, Appendix A).

The activities comprising the cost elements, Monitored Geologic Repository; Waste Acceptance, Storage and Transportation; and Nevada Transportation in Table 2-5 are described in this EIS. The last two elements are Program Integration and Institutional. Program Integration includes Quality Assurance (which is a mandatory program to identify and ensure implementation of requirements that protect the health and safety of the public, workers, and environment), Program Management and Integration, and non-Office of Civilian Radioactive Waste Management costs associated with the NRC, Nuclear Waste Technical Review Board, and the Nuclear Waste Negotiator. Institutional includes financial assistance for transportation planning. Details about the estimated costs are in *Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program* (DIRS 153255-DOE 2001, all) and *Life Cycle Cost Analysis for Repository Flexible Design Concepts* (DIRS 156900-DOE 2001, all). These reports provide further information on the basis of the estimates, time phasing of the expected expenditures, and the subdivision of the costs between the major activities noted in Table 2-5. For example, the cost to engineer and construct the repository would be approximately equivalent to the estimated program costs from 2002 to 2010 (proposed repository opening), or $8.3 to $9.1 billion (in 2001 dollars).

The most recent estimates show that approximately 70 percent of the repository-related costs would be paid from the Nuclear Waste Fund (fees collected by nuclear utilities from ratepayers) and about 30 percent from taxpayer revenues (primarily to pay for disposal of DOE spent nuclear fuel and high-level radioactive waste).